

## CHAPTER 5

### CRITICALITY RANKING – QUANTITATIVE AND QUALITATIVE

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#### 5-1. Criticality ranking

A *criticality ranking* is a list used to rank the failure modes of most concern first, down to the least concern, at the bottom. This procedure is essentially conducted in the same fashion whether it is a quantitative analysis or the more widely used qualitative (subjective) analysis.

a. When failure modes are analyzed in terms of RPN, the highest RPN must be listed first (qualitative analysis). When failure rate data is used to calculate criticality numbers (quantitative analysis) the highest criticality number should be listed first. See figure 5-1 for an example *failure mode criticality ranking* using DA Form 7613. Figure 5-2 using DA Form 7614 is another type of ranking that only ranks the *item criticality number* (equation 4-3) that was discussed in paragraph 4-4f. This is called an *item criticality ranking*. Both rankings have advantages but the *failure mode criticality ranking* provides the most detail regarding failure rates and failure modes and is therefore the preferred type when conducting a quantitative analysis.

b. The *failure mode criticality ranking*, *item criticality ranking*, and *RPN ranking* lists can be useful tools but should not be solely used to determine which items are of most concern. Where these rankings fall short are their inability to allow the analyst to be judgmental to determine higher risk or higher consequences of failures. It is quite possible that two or more failure modes have similar RPN's or criticality numbers, but one has a much higher severity or consequence of the failure. These items typically need to be addressed first. This is why it is highly suggested that this ranking should be complimented by developing a *criticality matrix*. The matrix is explained in the next section.

c. If the analysts do not wish to construct a criticality matrix, the next best approach would be to organize the Criticality Ranking by not only the Criticality Number or RPN, but also list the items by severity. This can be accomplished quite easily in an EXCEL program sorting first by severity and then by Criticality Number or RPN. The analysts can then review all of the higher severity items first and make sound judgments regarding what type of actions, if any, should be taken to decrease the severity. This critical ranking list is to be used in a flexible manner according to the best judgment of the analysts. If done correctly it will aid in safety, maintainability, and fault tree analysis, thereby enabling improvements in the design.

#### 5-2. Criticality matrix

The Criticality Matrix is a graphical or visual means of identifying and comparing failure modes for all components within a given system or subsystem and their probability of occurring with respect to severity. It is used for quantitative and qualitative analyses. The matrix can be used along with the Critical Item List or by itself in order to prioritize components.

a. The matrix has the distinctive ability to differentiate criticality of components with the same or similar RPN and criticality number. For example: two components could have the same RPN, one with the severity of three and an occurrence ranking of ten, the other with a severity of ten and an occurrence ranking of three, thus producing a RPN of 30. Consequently, listing them only by RPN would produce an equal ranking. By placing them in the matrix it becomes very evident that an item that is in the severity category of "ten" should take priority for some type of corrective action.

b. The matrix is constructed by inserting the assigned Item #, or other indicator, for each failure mode into matrix locations which represent the severity classification and probability of occurrence ranking. The criticality matrix example shown in figure 5-3 is representative of the HVAC system FMECA example in figure 4-5. If there is not sufficient space available in the matrix to paste the Item # then an alternative method to represent each failure mode should be used. The resulting matrix shows the relative ranking of criticality for each item's failures.

FAILURE MODE CRITICALITY RANKING (QUANTITATIVE)									
For use of this form, see TM 5-698-4; the proponent agency is USACE.									
SYSTEM: Mechanical System						DATE (YYYYMMDD): 20050819			
PART NAME: HVAC System						SHEET: 1 of 3			
REFERENCE DRAWING: C-20005-B						COMPILED BY: AAA			
MISSION: Provide Temperature Control to Room						APPROVED BY: BBB			
ITEM NUMBER	ITEM/FUNCTIONAL ID	POTENTIAL FAILURE MODES	FAILURE MECHANISM (CAUSE)	SEVERITY	FAILURE RATE $\lambda_p$ (SOURCE)	FAILURE EFFECT PROBABILITY ( $\beta$ )	FAILURE MODE RATIO ( $\alpha$ )	OPERATING TIME (t)	MODAL CRITICALITY NUMBER ( $C_M$ )
220.0	Chiller/ Remove heat(10°F) from chilled water supply	Degraded operation -remove less than 10°F	Refrig. loss, degraded comp., tube leak, dirty coil	3	9.2791x10-6 (single) NPRD-95 1.72x10-10 (redundant)	1	.92	61,320	9.70x10-6
310.2	Air Handler/ Provide 3200cfm of air, keep room at 72°F	Provide no air flow	broken belt, motor failure fan bearing seizure, Loss of power	3	1.7657x10-6 (single) NPRD-95 6.24x10-12 (redundant)	1	.25	61,320	9.56x10-8
220.1	Chiller/ Remove heat(10°F) from chilled water supply	remove no heat	compressor seizure, motor failure	4	9.2791x10-6 (single) NPRD-95 1.72x10-10 (redundant)	1	.08	61,320	8.45x10-6
110.0	Reservoir/ contain 6000 gallons of water	leak	Crack in wall	4	1.500x10-6 (single) .0104x10-6 (redundant)	1	1	61,320	6.38x10-4
120.1	Pump #1/ Transport Industrial water supply at 1000gpm	produce no water flow	broken coupling, suction line leak, motor inoperable	3	12.058x10-6 (single) NPRD-95 1.4x10-17 (redundant)	1	.65	61,320	5.58x10-13

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Figure 5-1. Example of DA Form 7613, Failure mode criticality ranking

FAILURE MODE CRITICALITY RANKING (QUANTITATIVE)									
For use of this form, see TM 5-698-4; the proponent agency is USACE.									
SYSTEM: Mechanical System						DATE (YYYYMMDD): 20050819			
PART NAME: HVAC System						SHEET: 2 of 3			
REFERENCE DRAWING: C-20005-B						COMPILED BY: AAA			
MISSION: Provide Temperature Control to Room						APPROVED BY: BBB			
ITEM NUMBER	ITEM/FUNCTIONAL ID	POTENTIAL FAILURE MODES	FAILURE MECHANISM (CAUSE)	SEVERITY	FAILURE RATE $\lambda_p$ (SOURCE)	FAILURE EFFECT PROBABILITY ( $\beta$ )	FAILURE MODE RATIO ( $\alpha$ )	OPERATING TIME (t)	MODAL CRITICALITY NUMBER ( $C_M$ )
210.1	Pump #5/ Transport chilled water supply at 960gpm	produce no water flow	broken coupling, suction line leak, motor inoperable	3	12.058x10 <sup>-6</sup> (single) NPRD-95 8.724x10 <sup>-10</sup> (redundant)	1	.65	61,320	5.58x10 <sup>-13</sup>
130.1	Cooling Tower #1/ maintain a water temp of 75°F.	Clogged sprayers	Untreated/unfiltered water	4	10.0518x10 <sup>-6</sup> (single) NPRD-95 1.3x10 <sup>-16</sup> (redundant)	1	.44	61,320	3.51x10 <sup>-12</sup>
120.0	Pump #1/ Transport Industrial water supply at 1000gpm	Transport water at a rate below 1000 gpm	Impeller degraded, gasket leak, motor degraded	3	12.058x10 <sup>-6</sup> (single) NPRD-95 1.4x10 <sup>-17</sup> (redundant)	1	.35	61,320	3.00x10 <sup>-13</sup>
210.0	Pump #5/ Transport chilled water supply at 960gpm	Degraded operation-produce water at a rate less than 960gpm	impeller degradation gasket leak, motor degraded	3	12.058x10 <sup>-6</sup> (single) NPRD-95 8.724x10 <sup>-10</sup> (redundant)	1	.35	61,320	3.00x10 <sup>-13</sup>
130.0	Cooling Tower #1/ maintain a water temp of 75°F.	Scaling (deposits) on media	Untreated water	4	10.0518x10 <sup>-6</sup> (single) NPRD-95 1.3x10 <sup>-16</sup> (redundant)	1	.36	61,320	2.87x10 <sup>-12</sup>

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Figure 5-1. Example of DA Form 7613, Failure mode criticality ranking (cont'd)

FAILURE MODE CRITICALITY RANKING (QUANTITATIVE)									
For use of this form, see TM 5-698-4; the proponent agency is USACE.									
SYSTEM: Mechanical System						DATE (YYYYMMDD): 20050819			
PART NAME: HVAC System						SHEET: 3 of 3			
REFERENCE DRAWING: C-20005-B						COMPILED BY: AAA			
MISSION: Provide Temperature Control to Room						APPROVED BY: BBB			
ITEM NUMBER	ITEM/FUNCTIONAL ID	POTENTIAL FAILURE MODES	FAILURE MECHANISM (CAUSE)	SEVERITY	FAILURE RATE $\lambda_p$ (SOURCE)	FAILURE EFFECT PROBABILITY ( $\beta$ )	FAILURE MODE RATIO ( $\alpha$ )	OPERATING TIME (t)	MODAL CRITICALITY NUMBER ( $C_M$ )
130.2	Cooling Tower #1/ maintain a water temp of 75°F.	Fan failure	Motor winding open, Loss of power to motor	3	10.0518x10-6 (single) NPRD-95 1.3x10-16 (redundant)	1	.20	61,320	1.54x10-12
310.1	Air Handler/ Provide 3200cfm of air to room, maintain	Provide airflow at a rate less than 3200cfm	reduced motor output, dirty intake filter	3	1.7657x10-6 (single) NPRD-95 6.24x10-12 (redundant)	1	.40	61,320	1.53x10-7
310.0	Air Handler/ Provide 3200cfm of air to room, maintain	Maintain air at a temp higher than 72°F	Dirty coils	3	1.7657x10-6 (single) NPRD-95 6.24x10-12 (redundant)	1	.35	61,320	1.34x10-7
130.0	Cooling Tower #1/ maintain a water temp of 75°F.	Scaling (deposits) on media	Untreated water	4	10.0518x10-6 (single) NPRD-95 1.3x10-16 (redundant)	1	.36	61,320	2.87x10-12

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Figure 5-1. Example of DA Form 7613, Failure mode criticality ranking (cont'd)

ITEM CRITICALITY RANKING (QUANTITATIVE)						
For use of this form, see TM 5-698-4; the proponent agency is USACE.						
SYSTEM: Mechanical System				DATE (YYYYMMDD): 20050819		
PART NAME: HVAC System				SHEET: 1 of 2		
REFERENCE DRAWING: C-20005-B				COMPILED BY: AAA		
MISSION: Provide Temperature Control to Room				APPROVED BY: BBB		
ITEM NUMBER	ITEM / FUNCTION	SEVERITY	FAILURE RATE $\lambda_p$ (SOURCE)	FAILURE EFFECT PROBABILITY ( $\beta$ )	OPERATING TIME (t)	ITEM CRITICALITY NUMBER ( $\Sigma C_M$ )
220.0	Chiller/ Remove heat(10°F) from chilled water supply	3	9.2791x10-6 (single) NPRD-95 1.72x10-10 (redundant)	1	61,320	9.70x10-6
120.0	Pump #1/ Transport water through Industrial water supply at 1000gpm	3	12.058x10-6 (single) NPRD-95 1.4x10-17 (redundant)	1	61,320	8.58x10-13
210.0	Pump #5/ Transport water through chilled water supply at 960gpm	3	12.058x10-6 (single) NPRD-95 8.724x10-10 (redundant)	1	61,320	8.58x10-13
220.1	Chiller/ Remove heat(10°F) from chilled water supply	4	9.2791x10-6 (single) NPRD-95 1.72x10-10 (redundant)	1	61,320	8.45x10-6
110.0	Reservoir/ contain 6000 gallons of water	4	1.500x10-6 (single)  .0104x10-6 (redundant)	1	61,320	6.38 x10-4

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Figure 5-2. Example of DA Form 7614, Item criticality ranking

ITEM CRITICALITY RANKING (QUANTITATIVE)						
For use of this form, see TM 5-698-4; the proponent agency is USACE.						
SYSTEM: Mechanical System				DATE (YYYYMMDD): 20050819		
PART NAME: HVAC System				SHEET: 2 of 2		
REFERENCE DRAWING: C-20005-B				COMPILED BY: AAA		
MISSION: Provide Temperature Control to Room				APPROVED BY: BBB		
ITEM NUMBER	ITEM / FUNCTION	SEVERITY	FAILURE RATE $\lambda_p$ (SOURCE)	FAILURE EFFECT PROBABILITY ( $\beta$ )	OPERATING TIME (t)	ITEM CRITICALITY NUMBER ( $\Sigma C_M$ )
130.0	Cooling Tower #1/ maintain a water temp of 75°F.	4	10.0518x10 <sup>-6</sup> (single) NPRD-95 1.3x10 <sup>-16</sup> (redundant)	1	61,320	6.38x10 <sup>-12</sup>
310.0	Air Handler/ Provide 3200cfm of air to room, maintain room at 72°F,	3	1.7657x10 <sup>-6</sup> (single) NPRD-95 6.24x10 <sup>-12</sup> (redundant)	1	61,320	3.826x10 <sup>-7</sup>
130.2	Cooling Tower #1/ maintain a water temp of 75°F.	3	10.0518x10 <sup>-6</sup> (single) NPRD-95 1.3x10 <sup>-16</sup> (redundant)	1	61,320	1.54x10 <sup>-12</sup>

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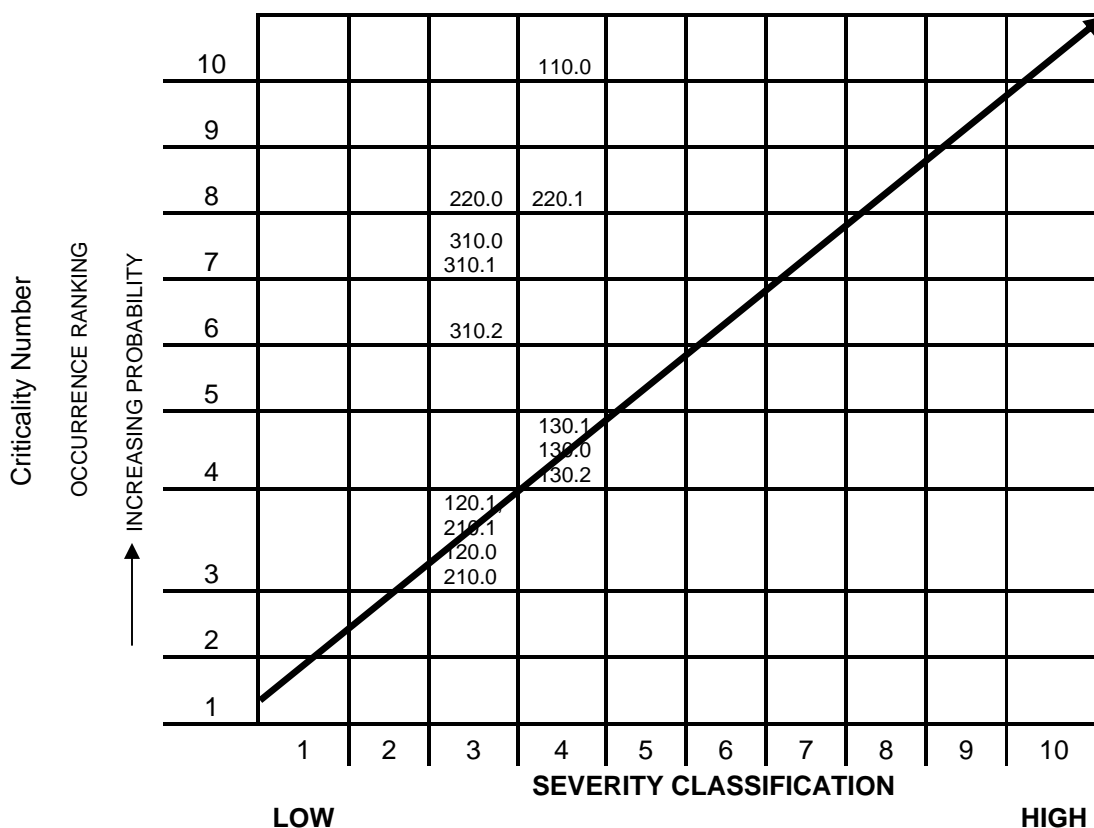
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Figure 5-2. Example of DA Form 7614, Item criticality ranking (cont'd)

c. Item #'s displayed in the upper most right hand corner of the matrix require the most immediate attention. These failures have a high probability of occurrence and a catastrophic effect on system operation or personnel safety. Therefore, they should be evaluated first to determine if a redesign (i.e., design in redundancy) is an alternative approach. As you move diagonally towards the lower left hand corner of the matrix, the criticality and severity of potential failures decreases. In cases where failures display the same relative severity and criticality, it must be determined whether safety/mission success or cost is the driving factor of the analysis. If safety/mission success is of more concern, items shown on the right of the diagonal line require the most re-design attention, because the effects of their failures are more severe even though their criticality ranking may be less. If cost is a major concern, items to the left of the diagonal line require attention, because the high criticality numbers (occurrence rankings) reflect higher failure probability.

d. By employing redundancy, a duplicate system is constructed such that it serves as a backup for a critical single point failure. Though the initial failure of the component or system cannot be avoided, the effect of the failure will no longer be catastrophic since a compensating provision (the redundant system) will serve to operate in its place. If redundancy cannot be employed, then a more robust component with a lower failure rate may be an option. Every means possible should be evaluated to lower the failure rate on any high severity classification failure mode. If this cannot be accomplished then a reaction plan must be developed in order to minimize the downtime of the system





Item #	Failure Mode	Modal Criticality Number
110.0	leak	$6.38 \times 10^{-4}$
120.0	Transport water at a rate below 1000 gpm	$3.00 \times 10^{-13}$
120.1	produce no water flow	$5.58 \times 10^{-13}$
130.0	Scaling(deposits) on media	$2.87 \times 10^{-12}$
130.1	Clogged sprayers	$3.51 \times 10^{-12}$
130.2	Fan failure	$1.54 \times 10^{-12}$
210.0	Degraded operation-produce water at a rate less than 960gpm	$3.00 \times 10^{-13}$
210.1	produce no water flow	$5.58 \times 10^{-13}$
220.0	Degraded operation-remove less than 10°F	$9.70 \times 10^{-6}$
220.1	remove no heat	$8.45 \times 10^{-6}$
310.0	Maintain air at a temp higher than 72°F	$1.34 \times 10^{-7}$
310.1	Provide airflow at a rate less than 3200cfm	$1.53 \times 10^{-7}$
310.2	Provide no air flow	$9.56 \times 10^{-8}$

Figure 5-3. Criticality matrix